Optimum Design of a Solar Desalination Process

IPRO 304-e

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Project Background

- Global Water Shortages
- Project Focus
Process Schematic

- SOLAR COLLECTOR
- EVAPORATOR
- CONDENSER
- Recycle
- Incoming salt water
- Product fresh water
- Brine
- Warm Air
- Cold Air
Project Outline

• Solar heater
• Evaporator
• Condenser
• Cost and sustainability
• Conclusion
Solar Collector

- Convert solar energy
- Constant exit temperature
- Minimize wasted energy
January Insolation
Solar Collector

- Convert solar energy
- Constant exit temperature
- Minimize wasted energy
Solar Unit
Assumptions

- No insolation losses
- No convective or radiative heat losses
- At start-up $T_{\text{bulk}} = T_{\text{win}}$
- No temperature gradient in bulk
- Quasi steady-state heat transfer coefficient
Mathematical Model

• Bulk heating

\[ V_b C_{pb} \rho_b \frac{dT_b}{dt} = A_b * Solar(t) \]

• Bulk temperature

\[ V_b C_{pb} \rho_b \frac{dT_b}{dt} = A_b * Solar(t) - hA(T_b - T_{ln}) \]

• Exit water temperature

\[ 0 = C_{pw} \rho_w F(t) * (T_{win} - T_{out}) + hA(T_b - T_{ln}) \]
Total Daily Flow

![Graph showing the flow (m³/sec) over time (sec).]
Evaporator Design

- Salt water enters, sprayed in tiny drops
- Pure water evaporates, leaves as water vapor
- Concentrated salt water exits
- Air flows countercurrent
Evaporator Design

Salt Water
T=90°C
M=18,400 lb/h

Humid Air
T=85°C
M=3100 lb/h

Brine
T=45°C
M=17,000 lb/h

Dry Air
T=35°C
M=1700 lb/h

Evaporator Schematic

Height
14 ft

Diameter
2.2 ft
Evaporator Design

- Select tower diameter
- Solve for height and cost
  - Heat transfer properties
  - Mass balance
- Adjust diameter to optimize cost and feasibility
- Results
  - Diameter: 2.2 ft
  - Height: 14.5 ft
  - Stainless steel
Condenser Design
General Information

- Transformation of water vapor to liquid by mechanical means

- Types
  - Shell and tube condenser
  - Spray condenser

- Spray Condenser
  - 1. Water inlet
  - 2. Spray
  - 3. Incondensables outlet
  - 4. Inlet of humid vapor
  - 5. Condensate outlet
Condenser Design
Specific Design Considerations

• Co-current flow
• Condensed water recycle stream used for spray water
  – Extra water only for start up
• Additional heat exchanger needed
  – Preheat salt water while cooling spray water

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimal Value</th>
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<tbody>
<tr>
<td>Minimum Height</td>
<td>11.45 ft (3.5m)</td>
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<tr>
<td>Diameter</td>
<td>2.0 ft (61 cm)</td>
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</table>
Condenser Design Calculations

- Volumetric air flow rate = 65534 ft³/hr
- Mass air flow rate = 1731 lbₘ/hr
- Volumetric flow rate of circulating water = 343.3 ft³/hr
- Mass flow rate of circulating water = 20630 lbₘ/hr

Mass flow rate of produced water:

\[
\dot{m}_{water\ produced} = \frac{\dot{m}_{circulating\ water} \cdot c_{pl} \cdot \Delta T_{water}}{\lambda_o} = 1432\ lb_m / hr
\]
Heat Exchanger

cold salt water
- Temperature: 15.00 °C
- Pressure: 101.3 kPa
- Molar Flow: 1396 kg mole/h

hot salt water
- Temperature: 20.00 °C
- Pressure: 101.3 kPa
- Molar Flow: 1396 kg mole/h

circulating H2O
- Temperature: 70.00 °C
- Pressure: 101.3 kPa
- Molar Flow: 538.5 kg mole/h

circulated cooled H2O
- Temperature: 57.10 °C
- Pressure: 101.3 kPa
- Molar Flow: 538.5 kg mole/h
Cost Analysis

• Used Seider’s *Process Design*
• Cylindrical process vessels and heat exchanger models
• Principal equipment cost \( (C_P) \) estimated
  – C & E : height & diameter
  – HE : heat exchange area
• Materials factor \( (F_M) \)
  – Carbon steel
  – Stainless steel
  – Titanium
• Compare costs
Comparative Costs & Investment

- Investment for project

<table>
<thead>
<tr>
<th>Our Investment:</th>
<th></th>
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<tbody>
<tr>
<td>Heat Exchanger</td>
<td>$41,881.97</td>
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<tr>
<td>Condenser: Carbon Steel</td>
<td>$98,187.94</td>
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<tr>
<td>Evaporator: Stainless Steel</td>
<td>$390,537.75</td>
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<tr>
<td>Miscellaneous Materials</td>
<td>$10,000.00</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$540,607.66</strong></td>
</tr>
</tbody>
</table>
Cost in the long run?

• Life of unit: 25 years
• Water producing days: 180

\[
\frac{5670 \text{ liters}}{\text{day}} \times \frac{180 \text{ day}}{\text{year}} \times 25 \text{ years} = 2.55 \times 10^7 \text{ liters}
\]

• Price of our water (worst case scenario)
  – January flow
  – \( \frac{1}{2} \) year production time

\[
\frac{\$540,607.66}{2.55 \times 10^7 \text{ liters}} = \$0.02/\text{liter}
\]
Feasibility & Sustainability

• Typical person uses 250 liters/day
  – Single person: $5/day or $160/month
• Current costs are lower in U.S.

• Q: Is this technology sustainable?
  – Green energy
  – Minimal impact on environment
  – Raw material plentiful
  – Cost still too high

• A: Yes, with water conservation and further development to make unit more cost effective
Conclusion

• Production: 5,670 L/day for test case
• Prohibitively expensive
• Model development and cost reduction